DOE attempted to quantify a range of uncertainties associated with mathematical models and input data, and estimated the potential effect these uncertainties could have on collective human health impacts. By summing the uncertainties discussed in Sections K.4.1, K.4.2, and K.4.3 where appropriate, DOE estimates that total collective impacts over 10,000 years could have been underestimated by as much as 3 or 4 orders of magnitude. However, because there are large uncertainties in the models used for quantifying the relationship between low doses (that is, less than 10 rem) and the accompanying health impacts, especially under conditions in which the majority of the populations would be exposed at a very low dose rate, the actual collective impact could be small.

On the other hand, impacts to individuals (human intruders) who could move to the storage sites and live close to the degraded facilities could be severe. During the early period (200 to 400 years after the assumed loss of institutional control), acute exposures to external radiation from the spent nuclear fuel and high-level radioactive waste material could result in prompt fatalities. In addition, after a few thousand years onsite shallow aquifers could be contaminated to such a degree that consumption of water from these aquifers could result in severe adverse health effects, including premature death. Uncertainties related to these localized impacts are related primarily to the inability to predict accurately how many individuals could be affected at each of the 77 sites over the 10,000-year analysis period. In addition, the uncertainties associated with localized impacts would exist for potential consequences resulting from disruptive events, both manmade and natural.

Therefore, as listed in Table K-15, uncertainties resulting from future changes in natural phenomena and human behavior that cannot be predicted, process model uncertainties, and dose-effect relationships, taken together, could produce the results presented in Section K.3, overestimating or underestimating the impacts by as much as several orders of magnitude. Uncertainties of this magnitude are typical of predictions of the outcome of complex physical and biological phenomena over long periods. However, these predictions (with their uncertainties) are valuable to the decisionmaking process because they provide insight based on the best information available.

REFERENCES

Note: In an effort to ensure consistency among Yucca Mountain Project documents, DOE has altered the format of the references and some of the citations in the text in this Final EIS from those in the Draft EIS. The following list contains notes where applicable for references cited differently in the Draft EIS.

104597	Battelle 1998	Battelle Pacific Northwest Division 1998. *Analytical Approach for Estimating Releases of Spent Nuclear Fuel and High-Level Waste for the Yucca Mountain Environmental Impact Statement No-Action Alternative*. Las Vegas, Nevada: Jason Technologies. ACC: MOL.19990513.0039.
101533	Buck et al. 1995	Buck, J.W.; Whelan, G.; Droppo, J.G., Jr.; Strenge, D.L.; Castleton, K.J.; McDonald, J.P.; Sato, C.; and Streile, G.P. 1995. *Multimedia Environmental Pollutant Assessment System (MEPAS) Application Guidance, Guidelines for Evaluating MEPAS Input Parameters for Version 3.1*. PNL-10395. Richland, Washington: Pacific Northwest Laboratory. TIC: 242139.
152471	Bureau of the Census 2000	Bureau of the Census 2000. "National Population Projections I. Summary Files." Washington, D.C.: Bureau of the Census. Accessed August 28, 2000. ACC: MOL.20010725.0152. http://www.census. gov/population/www/projections/natsum-T1.html

103177	CP&L 1989	CP&L (Carolina Power and Light Company) 1989. *Brunswick Steam Electric Plant Independent Spent Fuel Storage Installation Safety Analysis Report*. Raleigh, North Carolina: Carolina Power and Light Company. TIC: 3933.
103168	Chanin and Young 1998	Chanin, D. and Young, M.L. 1998. *Code Manual for MACCS2. Preprocessor Codes COMIDA2, FGRDCF, IDCF2*. NUREG/CR-6613, Vol. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 243881.
104603	CRWMS M&O 1995	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1995. *Preliminary Dose Assessment for the MGDS Surface Facility Waste Handling Operations*. B00000000-01717-5705-00022 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981202.0431. In the Draft EIS, this reference was cited as TRW 1995 in Appendix K.
100355	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Introduction." Chapter 1 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00001 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL. 19981008.0001. In the Draft EIS, this reference was cited as TRW 1998m in Appendix K.
100356	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Unsaturated Zone Hydrology Model." Chapter 2 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00002 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0002. In the Draft EIS, this reference was cited as TRW 1998n in Appendix K.
100357	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Thermal Hydrology." Chapter 3 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00003 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0003. In the Draft EIS, this reference was cited as TRW 1998o in Appendix K.
100358	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Near-Field Geochemical Environment." Chapter 4 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00004 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0004. In the Draft EIS, this reference was cited as TRW 1998p in Appendix K.

100359	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Waste Package Degradation Modeling and Abstraction." Chapter 5 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00005 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0005. In the Draft EIS, this reference was cited as TRW 1998q in Appendix K.
100362	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Waste Form Degradation, Radionuclide Mobilization, and Transport Through the Engineered Barrier System." Chapter 6 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00006 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0006. In the Draft EIS, this reference was cited as TRW 1998k in Appendix K.
100364	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Unsaturated Zone Radionuclide Transport." Chapter 7 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document.* B00000000-01717-4301-00007 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0007. In the Draft EIS, this reference was cited as TRW 1998r in Appendix K.
100365	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Saturated Zone Flow and Transport." Chapter 8 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00008 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0008. In the Draft EIS, this reference was cited as TRW 1998s in Appendix K.
100366	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Biosphere." Chapter 9 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document.* B00000000-01717-4301-00009 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL. 19981008.0009. In the Draft EIS, this reference was cited as TRW 1998t in Appendix K.
100369	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Disruptive Events." Chapter 10 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00010 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0010. In the Draft EIS, this reference was cited as TRW 1998u in Appendix K.

100371	CRWMS M&O 1998	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. "Summary and Conclusions." Chapter 11 of *Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document*. B00000000-01717-4301-00011 REV 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981008.0011. In the Draft EIS, this reference was cited as TRW 1998v in Appendix K.
103711	Davis, Strenge, and Mishima 1998	Davis, P.R.; Strenge, D.L.; and Mishima, J. 1998. *Accident Analysis for Continued Storage*. Las Vegas, Nevada: Jason Technologies Corporation. ACC: MOL. 20001010.0214.
101556	Davis 1998	Davis, R.G., Jr. 1998. *Direct Exposure from Degrading Commercial Spent Nuclear Fuel Storage*. Aiken, South Carolina: Tetra Tech NUS. TIC: 241173.
102588	DOE 1992	DOE (U.S. Department of Energy) 1992. *Characteristics of Potential Repository Wastes.* DOE/RW-0184-R1. Four volumes. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: HQO.19920827.0001; HQO.19920827.0002; HQO.19920827.0003; HQO.19920827.0004.
104601	DOE 1993	DOE (U.S. Department of Energy) 1993. *Recommendations for the Preparation of Environmental Assessments and Environmental Impact Statements*. Washington, D.C.: U.S. Department of Energy, Office of NEPA Oversight. ACC: HQX.19930623.0005.
101810	DOE 1996	DOE (U.S. Department of Energy) 1996. *DOE Standard, Accident Analysis for Aircraft Crash into Hazardous Facilities*. DOE-STD-3014-96. Washington, D.C.: U.S. Department of Energy. TIC: 231519.
101779	DOE 1998	DOE (U.S. Department of Energy) 1998. *Viability Assessment of a Repository at Yucca Mountain*. DOE/RW-0508. Overview and five volumes. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19981007.0027; MOL.19981007.0028; MOL.19981007.0029; MOL.19981007.0030; MOL.19981007.0031; MOL.19981007.0032.
153849	DOE 2001	DOE (U.S. Department of Energy) 2001. *Yucca Mountain Science and Engineering Report.* DOE/RW-0539. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.20010524.0272.
101819	EPA 1988	EPA (U.S. Environmental Protection Agency) 1988. *Superfund Exposure Assessment Manual.* EPA/504/1-88/001. Washington, D.C.: U.S. Environmental Protection Agency. TIC: 241178.

101820	EPA 1991	EPA (U.S. Environmental Protection Agency) 1991. *Human Health Evaluation Manual, Supplemental Guidance, "Standard Default Exposure Factors" Interim Final.* Volume 1 of *Risk Assessment Guidance for Superfund*. OSWER Directive 9285.6-03. Washington, D.C.: U.S. Environmental Protection Agency. TIC: 237188.
147927	ICRP 1966	ICRP (International Commission on Radiological Protection) 1966. "The Evaluation of Risks from Radiation." *Annals of the ICRP*. ICRP Publication 8. London, England: Pergamon Press. TIC: 241602.
110386	ICRP 1979	ICRP (International Commission on Radiological Protection) 1979. *Limits for Intakes of Radionuclides by Workers*. Volume 2, No. 3/4 of *Annals of the ICRP*. Sowby, F.D., ed. ICRP Publication 30 Part 1. New York, New York: Pergamon Press. TIC: 4939.
101836	ICRP 1991	ICRP (International Commission on Radiological Protection) 1991. "1990 Recommendations of the International Commission on Radiological Protection." Volume 21, No. 1-3 of *Annals of the ICRP*. ICRP Publication 60. New York, New York: Pergamon Press. TIC: 235864.
101852	Jenkins 1998	Jenkins, A.T. 1998. *Groundwater Transport Conditions Near Commercial Reactors and DOE Sites*. Oak Ridge, Tennessee: Tetra Tech NUS. TIC: 241175.
101897	Jow et al. 1990	Jow, H-N.; Sprung, J.L.; Rollstin, J.A.; Ritchie, L.T.; and Chanin, D.I. 1990. *Model Description*. Volume 2 of *MELCOR Accident Consequence Code System (MACCS)*. NUREG/CR-4691. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 236740. In the Draft EIS, this reference was cited as Rollstin, Chanin, and Jow 1990 in Appendix K.
103776	Kennedy and Strenge 1992	Kennedy, W.E. and Strenge, D.L. 1992. *Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*. Volume 1 of *Residual Radioactive Contamination from Decommissioning*. NUREG/CR-5512. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 234470.
100464	Leigh et al. 1993	Leigh, C.D.; Thompson, B.M.; Campbell, J.E.; Longsine, D.E.; Kennedy, R.A.; and Napier, B.A. 1993. *User's Guide for GENII-S: A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment*. SAND91-0561. Albuquerque, New Mexico: Sandia National Laboratories. TIC: 231133.
147905	Mishima 1998	Mishima, J. 1998. "Potential Airborne Release of Particulate Materials During Degradation of Commercial Spent Nuclear Fuel." Memorandum from J. Mishima (Jason Technologies Corporation) to E. Rollins (Tetra Tech NUS), August 20, 1998. TIC: 241186.

101835	Mossman et al. 1996	Mossman, K.; Goldman, M.; Masse, F.; Mills, W.A.; Schiager, K.J.; and Vetter, R.J. 1996. *Radiation Risk in Perspective-Position Statement of the Health Physics Society.* McLean, Virginia: Health Physics Society. TIC: 242187. In the Draft EIS, this reference was cited as HPS 1996 in Appendix K.
100018	National Research Council 1995	National Research Council 1995. *Technical Bases for Yucca Mountain Standards*. Washington, D.C.: National Academy Press. TIC: 217588.
101849	NCHS 1993	NCHS (National Center for Health Statistics) 1993. "Advance Report of Final Mortality Statistics, 1990." *Monthly Vital Statistics Report, 41*, (7, Supplement). Atlanta, Georgia: Centers for Disease Control and Prevention. TIC: 241180.
101856	NCRP 1993	NCRP (National Council on Radiation Protection and Measurements) 1993. *Limitation of Exposure to Ionizing Radiation*. NCRP Report No. 116. Bethesda, Maryland: National Council on Radiation Protection and Measurements. TIC: 207090.
101857	NCRP 1993	NCRP (National Council on Radiation Protection and Measurements) 1993. *Risk Estimates for Radiation Protection*. NCRP Report No. 115. Bethesda, Maryland: National Council on Radiation Protection and Measurements. TIC: 232971.
101858	NCRP 1995	NCRP (National Council on Radiation Protection and Measurements) 1995. *Principles and Application of Collective Dose in Radiation Protection*. NCRP Report No. 121. Bethesda, Maryland: National Council on Radiation Protection and Measurements. TIC: 225254.
101884	NCRP 1997	NCRP (National Council on Radiation Protection and Measurements) 1997. *Uncertainties in Fatal Cancer Risk Estimates Used in Radiation Protection*. NCRP Report No. 126. Bethesda, Maryland: National Council on Radiation Protection and Measurements. TIC: 237631.
100067	NRC 1977	NRC (U.S. Nuclear Regulatory Commission) 1977. Regulatory Guide 1.109, Rev. 1. 1977. *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I.* Washington, D.C.: U.S. Nuclear Regulatory Commission. Readily available. ACC: NNA.19870806.0032
101898	NRC 1991	NRC (U.S. Nuclear Regulatory Commission) 1991. *Environmental Assessment Related to Construction and Operation of the Calvert Cliffs Independent Spent Fuel Storage Installation, Docket No. 72-8 (50-317, -318) Baltimore Gas and Electric Company*. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 241726.
147915	NRC 1991	NRC (U.S. Nuclear Regulatory Commission) 1991. *Standard Format and Content of a License Application for a Low-Level Radioactive Waste Disposal Facility*. NUREG-1199, Rev. 2. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 241169.

106184	NRC 1996	NRC (U.S. Nuclear Regulatory Commission) 1996. Regulatory Guide 8.29, Rev. 1. 1996. *Instruction Concerning Risks from Occupational Radiation Exposure.* Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 237388.
104596	Orthen 1999	Orthen, R.F., Jr. 1999. *Health, Safety, and Environmental Impacts During Controlled Long-Term Storage of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*. Aiken, South Carolina: Tetra Tech NUS. ACC: MOL.19990608.0047.
103449	PGE 1996	PGE (Portland General Electric) 1996. *Trojan Independent Spent Fuel Storage Installation, Safety Analysis Report*. PGE-1069. Portland, Oregon: Portland General Electric. TIC: 243815.
101910	Poe 1998	Poe, W.L., Jr. 1998. *Long-Term Degradation of Concrete Facilities Presently Used for Storage of Spent Nuclear Fuel and High-Level Waste*. Revision 1. Las Vegas, Nevada: Jason Technologies. TIC: 244048.
101911	Poe 1998	Poe, W.L., Jr. 1998. *Regional Binning for Continued Storage of Spent Nuclear Fuel and High-Level Wastes*. Las Vegas, Nevada: Jason Technologies. TIC: 244049.
101912	Poe and Wise 1998	Poe, W.L., Jr. and Wise, P.F. 1998. *Documentation of National Weather Conditions Affecting Long-Term Degradation of Commercial Spent Nuclear Fuel and DOE Spent Nuclear Fuel and High-Level Waste*. Las Vegas, Nevada: Jason Technologies. TIC: 244115.
101917	Rollins 1998	Rollins, E.M. 1998. *Evaluation of Multimedia Environmental Transport Models for Use in the Yucca Mountain Environmental Impact Statement No-Action Alternative*. Aiken, South Carolina: Tetra Tech NUS. ACC: MOL.20001010.0213.
150990	Rollins 1998	Rollins, E.M. 1998. *Bounding Impacts Resulting from Contaminated Floodplains.* Aiken, South Carolina: Tetra Tech NUS. TIC: 244051.
147923	RSIC 1991	RSIC (Radiation Shielding Information Center) 1991. *ORIGEN 2.1, Isotope Generation and Depletion Code, Matrix Exponential Method.* RSIC Computer Code Collection. CCC-371, Oak Ridge, Tennessee: Oak Ridge National Laboratory. ACC: MOV.19970212.0145. In the Draft EIS, this reference was cited as ORNL 1991 in Appendix K.
147925	Shipers and Harlan 1989	Shipers, R.L. and Harlan, C.P. 1989. *Assessment of Relative Significance of Migration and Exposure Pathways*. Volume 2 of *Background Information for the Development of a Low-Level Waste Performance Assessment Methodology*. NUREG/CR-5453. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 226554.
101925	Sinkowski 1998	Sinkowski, D.S. 1998. *Population Affected from Continued Storage and Degradation of Spent Nuclear Fuel and High Level Waste*. Las Vegas, Nevada: Jason Technologies. TIC: 241166.

101937	Toblin 1998	Toblin, A.L. 1998. *Near Field Groundwater Transport and Gardener Dose Consequence*. Gaithersburg, Maryland: Tetra Tech NUS. TIC: 241177.
101935	Toblin 1999	Toblin, A.L. 1999. *Radionuclide Transport and Dose Commitment from Drinking Water from Continued Storage and Degradation of Spent Nuclear Fuel and High Level Waste Materials Under Loss of Institutional Control.* Gaithersburg, Maryland: Tetra Tech NUS. TIC: 244116.
101936	Toblin 1999	Toblin, A.L. 1999. *All Water Pathway Analysis from Continued Storage and Degradation of Spent Nuclear Fuel and High Level Waste Materials Under Loss of Institutional Control*. Gaithersburg, Maryland: Tetra Tech NUS. TIC: 244117.